Renal and visceral protection in thoracoabdominal aortic surgery

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Objectives: Open thoracoabdominal aortic aneurysm (TAAA) repair traditionally carries substantial perioperative morbidity and mortality, primarily from distal aortic ischemia. Advances in surgical techniques, adjuncts, and strategies have greatly improved outcomes.

Methods: We analyzed outcomes of 1267 open consecutive TAAA repairs between January 2005 and September 2013. We provided cold crystalloid renal perfusion whenever the renal ostia were accessible; according to extent of repair, we selectively used left heart bypass and provided isothermic blood to the celiac axis and superior mesenteric artery. Repair was extensive (Crawford extent I and II) in 717 cases (57%). Left heart bypass was used in 645 (51%) cases, cold crystalloid renal perfusion in 987 (78%), and isothermic visceral perfusion in 318 (25%). Additional patient-specific surgical adjuncts included endarterectomy of renal or visceral vessels, open stent placement within these vessels, or use of both techniques; at least one was used in 447 repairs (35%).

Results: Thirty-day survival was 95% (1198/1267); overall operative mortality was 8% (104/1267). Acute renal dysfunction occurred in 155 (12%), renal failure requiring hemodialysis at hospital discharge in 84 (7%), and bowel ischemia in 9 (<1%). Extent II and III TAAA repairs carried the highest risks of postoperative renal dysfunction and renal failure requiring hemodialysis at hospital discharge.

Conclusions: Contemporary protective strategies allow open TAAA repair with substantially fewer renal and visceral ischemic complications. Although bowel ischemia is uncommon, renal failure remains a concern, especially in extent II and extent III TAAA repairs. Additional studies are needed to identify and improve renal protection strategies. (J Thorac Cardiovasc Surg 2014;148:2963-6)

Open repair of thoracoabdominal aortic aneurysm (TAAA) traditionally carries a formidable risk of perioperative morbidity and mortality, primarily as a result of distal aortic ischemia during repair. Although renal dysfunction after TAAA repair occurs in as many as 28% of patients, it necessitates postoperative dialysis in 4% to 11% of cases.[1-5] Preoperative renal impairment and postoperative renal complications are commonly associated with worsened long-term survival[6] and increased postoperative mortality.[4-9] Although cases of nonrenal visceral and bowel ischemia after TAAA repair are fortunately uncommon, they have been associated with substantial mortality and morbidity.[9,10] Recent advances in surgical techniques and adjuncts have significantly improved surgical outcomes after open TAAA repair.[2,8,11-13] We provide a review of state-of-the-art approaches to renal and visceral protection and report our contemporary experience with open TAAA repair.

For decades, surgeons have developed several perfusion strategies to minimize the ischemic damage to the downstream organs while the aorta is clamped. One strategy is the use of a passive shunt to provide distal aortic perfusion. Its potential advantage lies in providing pulsatile arterial flow to distal organs. This technique is infrequently used because of the popularity of mechanical circulatory support and an inherent inability to conveniently adjust flow rates or distal aortic pressure. Passive shunting to deliver inline mesenteric perfusion combined with cold crystalloid renal perfusion to maintain a core renal temperature at 25°C has produced satisfactory results.[5]

With the advancement of extracorporeal circulation technology, two primary approaches have emerged to maintain distal aortic perfusion and provide selective visceral perfusion. The first uses a left heart bypass (LHB) circuit.[1,3,7-9] LHB can be used to maintain distal perfusion and pressure and be adjusted as needed to sustain stable hemodynamics. We use LHB as a closed circuit with the addition of a reservoir to salvage shed blood. LHB use is associated with an increased incidence of postoperative renal failure[14] and isothermic visceral and renal perfusion[15] was a concern in some initial studies. Jacobs and associates[16] postulated that this may be due to inadequate renal perfusion pressure. They proposed using catheters equipped with pressure channels to maintain the perfusion pressure at 60 mm Hg or higher, particularly

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Abbreviations and Acronyms

LHB = left heart bypass
TAAA = thoracoabdominal aortic aneurysm

in patients with chronic hypertension or chronic renal insufficiency (eg, 85 mm Hg).

Various strategies to provide selective visceral perfusion from modified LHB circuits have been described[8,12,17] in TAAA repair. Hassoun and coworkers[8] compared the outcomes of either isothermic (37°C) or cold blood (4°C) visceral perfusion of all 4 branching arteries. Of the 347 patients studied, 81 (23%) had development of acute renal failure. Similar acute renal failure rates were found among patients receiving the different perfusion strategies; however, a significantly lower in-hospital mortality was found when using cold blood (27% vs 56%; $P < .02$).

In addition, during TAAA repair, full cardiopulmonary bypass may be used with a wide range of protective hypothermia strategies, such as mild (34°C) to profound (18°C) systemic hypothermia, during the repair. Partial cardiopulmonary bypass, with 3 roller pumps for femoral-femoral bypass, celiac axis and superior mesenteric artery perfusion, and bilateral renal perfusion, may also be used.[18] Kulik and colleagues[2] recently reported their experience with extent I, II, and III TAAA repairs performed with cardiopulmonary bypass and deep hypothermic (22°C or lower) circulatory arrest, with a 7% incidence (n = 15) of new-onset acute renal failure necessitating dialysis out of 218 patients. More than half of these patients receiving dialysis died after multisystem organ dysfunction, but only 4% of early survivors required temporary dialysis.

Our current approach to renal and visceral protection for repair of TAAA has evolved from the results of 2 of our randomized clinical trials[11,12] and has been described in recent publications.[19,20] In the first trial, we compared postoperative renal dysfunction in patients receiving either isothermic blood or cold crystalloid for renal perfusion.[11] After multivariate analysis, we found that cold crystalloid perfusion independently protected against renal dysfunction.[11]

Subsequently, we compared renal outcomes in patients receiving either cold blood or cold crystalloid for renal perfusion.[12] We found no significant difference between patients with regard to renal failure or early death; however, we noted a statistically nonsignificant trend toward less paraplegia in the cold crystalloid group.

Currently, we apply a multimodal approach to renal and visceral protection. We use moderate heparinization (1 mg/kg) and mild passive hypothermia (nasopharyngeal temperature near 33°C) in all repairs. Whenever there is access to renal artery ostia, we use intermittent cold crystalloid perfusion. Generally, to provide renal perfusion we prefer to use cold crystalloid, rather than cold blood, as it is less cumbersome to use because an LHB circuit is not needed. We add mannitol (12.5 g/L) and methylprednisolone (125 mg/L) to the Ringer's lactate solution, cool the perfusate to 4°C, and administer it with a separate roller head pump connected to balloon-tip perfusion catheters. An initial bolus of 200 to 300 mL of cold crystalloid perfusate is administered per kidney, followed by intermittent infusion of 100 to 150 mL per kidney delivered every 10 to 15 minutes until arterial flow is reestablished. The volume and frequency are adjusted to avoid fluid overload and hypothermia (>32°C temperature).

For extent I and II repairs, we routinely use LHB, maintaining the flows at 1.5 to 2.5 L/min. After the completion of proximal anastomosis, LHB is stopped, and the remaining aortic aneurysm is opened. During reconstruction, the celiac axis and superior mesenteric artery are perfused through balloon perfusion catheters with isothermic blood from the LHB circuit. A continuous selective perfusion with isothermic blood is delivered at a total flow rate of 300 to 500 mL/min until the balloon catheters are removed near completion of the visceral anastomosis.

Recent aortic guidelines recommend the use of cold blood or cold crystalloid renal perfusion (class IIB, level of evidence B)[21]; however, the technique and addition of various additives cause this perfusion to vary among centers. A recent study compared the renal perfusion strategy of using cold crystalloid solution enriched with histidine-tryptophan-ketoglutarate with cold Ringer's lactate solution in patients undergoing open TAAA repair. After 1:1 propensity score matching of 42 patients in each group, the observed freedom from acute kidney injury was significantly greater in the histidine-tryptophan-ketoglutarate group (38.1%) than in the Ringer's lactate solution group (9.5%; $P = .002$), despite longer total renal ischemic time in the former group.[22] Currently a phase II, randomized, placebo-controlled, double-blind study is in progress to evaluate the role of a hypoxia-inducible factor prolyl-hydroxylase inhibitor in reducing ischemic events in patients undergoing thoracoabdominal and descending thoracic aortic aneurysm repair.[23]

A significant proportion of patients with TAAA have concomitant visceral and renal artery occlusive disease.[24] To improve blood flow through occluded visceral arteries, endarterectomy may be performed, or balloon-expandable stents may be used.[25] The experience of Svensson and associates[14,24] demonstrated that renal endarterectomy is associated with significantly less renal failure in patients with preexisting renal dysfunction. Additionally, although all 4 of the branching visceral arteries are commonly attached as an island patch, individual small-diameter grafts may be used as necessary to bypass the visceral vessels; this is particularly useful if the left renal artery becomes widely

TABLE 1. Techniques of renal and visceral perfusion and outcomes in 1267 patients undergoing open thoracoabdominal aortic aneurysm repair (January 2005-September 2013)

	All patients (n = 1267)	Extent I (n = 319)	Extent II (n = 398)	Extent III (n = 261)	Extent IV (n = 289)
Protective technique (no.)					
Left heart bypass	645 (51%)	262 (82%)	355 (89%)	26 (10%)	2 (1%)
Selective celiac or SMA perfusion	318 (25%)	37 (12%)	255 (64%)	20 (8%)	6 (2%)
Cold crystalloid renal perfusion	987 (78%)	121 (38%)	357 (90%)	232 (89%)	277 (96%)
Hypothermic circulatory arrest	28 (2%)	17 (5%)	10 (3%)	1 (<1%)	0
Perfusion and ischemic times (min, median and interquartile range)					
Left-heart bypass time	25 (19-30)	27 (21-31)	23 (17-30)	20 (17-27)	19 (14-23)
Right kidney					
Total ischemic time	45 (33-58)	45 (36-54)	60 (51-71)	37 (31-46)	33 (27-43)
Unprotected ischemic time	33 (26-43)	24 (17-31)	40 (33-48)	36 (30-44)	33 (26-43)
Left kidney					
Total ischemic time	49 (37-64)	45 (36-55)	64 (54-79)	44 (35-56)	40 (30-51)
Unprotected ischemic time	37 (27-50)	25 (17-31)	44 (35-56)	42 (33-54)	40 (30-50)
Celiac axis					
Total ischemic time	45 (34-58)	45 (36-54)	59 (50-70)	39 (32-47)	33 (26-43)
Unprotected ischemic time	34 (26-43)	24 (17-31)	39 (32-48)	37 (30-46)	33 (26-43)
Superior mesenteric artery					
Total ischemic time	45 (34-58)	45 (37-54)	59 (50-70)	39 (32-47)	33 (26-43)
Unprotected ischemic time	33 (26-43)	24 (17-31)	39 (32-48)	37 (30-46)	33 (26-43)
Patient-specific adjuncts for renal and visceral vessels (no.)					
Endarterectomy	396 (31%)	22 (7%)	110 (28%)	119 (46%)	145 (50%)
Placement of stent	159 (13%)	9 (3%)	47 (12%)	44 (17%)	59 (20%)
Endarterectomy or stent or both	447 (35%)	27 (8%)	126 (32%)	130 (50%)	164 (57%)
Outcomes (no.)					
Acute renal dysfunction	155 (12%)	29 (9%)	66 (17%)	34 (13%)	26 (9%)
Renal failure requiring dialysis at hospital discharge	84 (7%)	10 (3%)	36 (9%)	23 (9%)	15 (5%)
Bowel ischemia	9 (1%)	0	2 (1%)	5 (2%)	2 (1%)

Total ischemic time is defined as the interval between application of the initial aortic crossclamp and restoration of normal blood flow to a region; unprotected ischemic time is defined as the region's total ischemic time minus the time that region was perfused during left heart bypass or selective visceral or renal perfusion. All the presented data vary significantly depending on the extent of repair ($P \leq .05$). *SMA*, Superior mesenteric artery.

separated from other visceral vessels or if the ostia of other visceral vessels are so far apart that island patch reimplantation would not be appropriate.[20]

The use of visceral stents in treating renal and mesenteric occlusive disease in patients undergoing TAAA repair is a relatively new strategy to enhance visceral perfusion.[25] Visceral stents are useful in obliterating the false lumen in concomitant aortic dissection, securing the intimal edges after endarterectomy, facilitating the safe placement of balloon catheters, and helping to keep the ostia patent near the patch anastomosis. Although these adjuncts are usually safe and effective, some of the drawbacks include difficultly in safely manipulating a friable arterial wall after endarterectomy, time-consuming individual branch anastomoses, possibility of vessel perforation or stent migration after the stent deployment, and risk of thrombosis.

Of 1267 contemporary open TAAA repairs, 411 (32%) involved separate small-diameter grafts for left renal artery bypasses, 192 (15%) for right renal artery bypasses, and 125 (10%) for celiac artery or superior mesenteric artery bypasses. Either endarterectomy or stents were used in 447 (35%) repairs (Table 1). The operative mortality was 8%, similar to that in our previously published reports. Although the overall incidence of acute renal dysfunction was 12%, only 7% of repairs necessitated dialysis at the time of discharge. The incidence of renal dysfunction was highest after extent II TAAA repair, which correlates with prolonged protected and unprotected renal ischemia times (Table 1). Although bowel ischemia occurred in only 9 (1%) patients, it had a substantial attendant mortality of 88% (8 of 9 patients).

Contemporary protective strategies enable patients to undergo open TAAA repair with substantially fewer renal and visceral ischemic complications than in previous decades. The risk of renal failure, however, especially in extent II and extent III TAAA repairs, remains a concern because of the poor long-term prognosis of these patients. Additional studies are needed to identify and improve renal protection strategies for patients undergoing open TAAA repair.

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